ON THE NUMBER OF RAYS IN ASTERIAS TENUISPINA LAMK. AT BERMUDA[1]

BY W. J. CROZIER

HARVARD UNIVERSITY

I. It was suggested by Clark (1901) that the average number of rays borne by *Asterias tenuispina* was different for separate localities in Bermuda. He examined forty specimens of this species—eleven from Coney Island and twenty-nine from Harrington Sound; in the first set the average number of rays was 5.91 (I find the mode to be 6), in the second set 6.93 (with a mode of 7). If this condition really obtains, it would be an exceedingly interesting matter to determine the factors responsible for this sort of difference. I have therefore examined a number of *Asterias* (312 in all) from several localities in the Bermudas, namely: Agar's Island, Spanish Point, Hawkins Island, Ely's Harbor, Hungry Bay, Harrington Sound and Coney Island; the first four are situated on the periphery of Great Sound, the others at widely removed points on the north and south shores. For the identification of these places, references may be made to the maps published by Mark (1905).

These observations were made at the Bermuda Biological Station, mostly during the summer of 1914.

II. The first lot of starfishes was collected in the immediate vicinity of Agar's Island in 1913. The number of rays varied from 2 to 9; the frequency distribution is given in Fig. 1. The modal number of rays is clearly 7. In 1914 a collection of *Asterias* from this place gave the ray frequency distribution shown in Fig. 2, where the modal number of rays is again 7. Collections, during 1914, at the other stations named gave the following ray frequency counts:

[1] Contributions from the Bermuda Biological Station for Research, No. 35.

Station and Year	No. of Specimens	Modal Ray Number	See Figure
Agar's Isl., 1913	43	7	1
Agar's Isl., 1914	62	7	2
Spanish Point, 1914	33	7	3
Hawkins Isl., 1914	39	7	4
Ely's Harbor, 1914	36	7	5
Hungry Bay, 1914	41	7	6
Coney Island, 1914	20	7	7
Harrington Sound, 1914	38	7	8

The modal number of rays is in each case 7. This is true for the same locality in two successive years, for near-by localities and for places widely enough separated

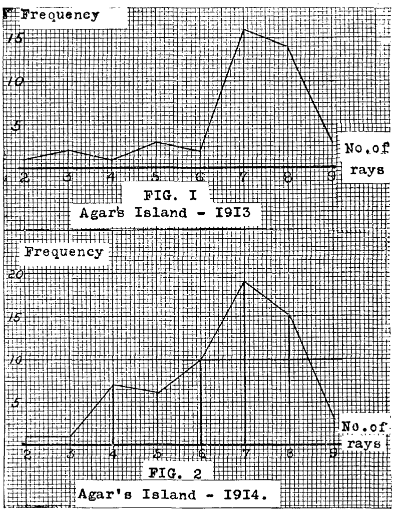


FIG. I
Agar's Island - 1913
FIG. 2
Agar's Island - 1914.

to yield critical data relative to the suggestion which prompted this inquiry. For the total population examined the ray frequency distribution, which of course gives a mode of 7 rays, is plotted in Fig. 3. It is to be noted further that according to Ludwig (1897, p. 345) the most common number of rays in *A. tenuispina* from the Mediterranean is also 7.

III. It has been observed by every one who has studied *A. tenuispina* that in most of the individuals the rays occur in two groups, those of one group being longer than those in the other, though within each group the rays are of about the same length. This condition is evident in 259 (83.6 per cent.) of my specimens. There is general

agreement (cf. Ludwig, 1897, and Ritter and Crocker, 1900), that in some cases, if not in all, "this disparity in size is due to the regeneration of halves of automatically bisected animals." My observations fully confirm this. I have witnessed, as did Ludwig, several cases of spon-

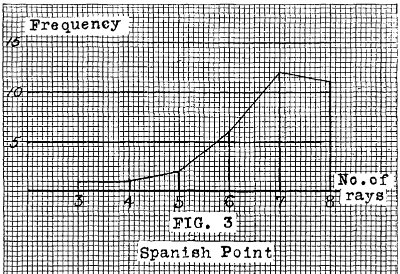


FIG. 3
Spanish Point

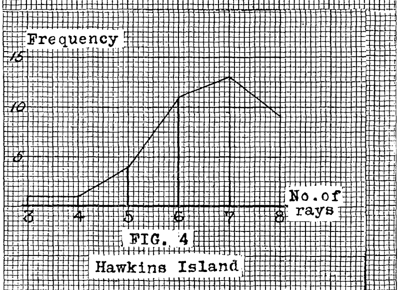


FIG. 4
Hawkins Island

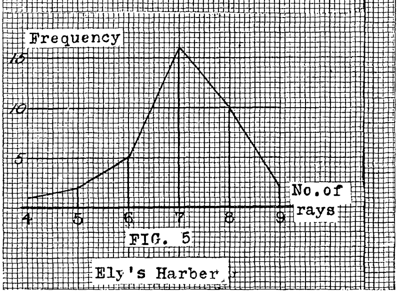


FIG. 5
Ely's Harber

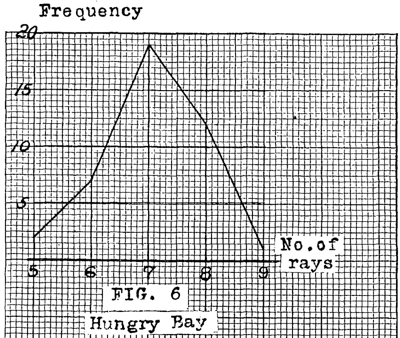


FIG. 6
Hungry Bay

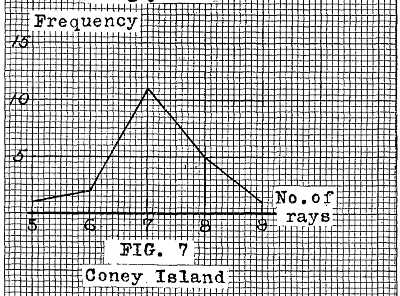


FIG. 7
Coney Island

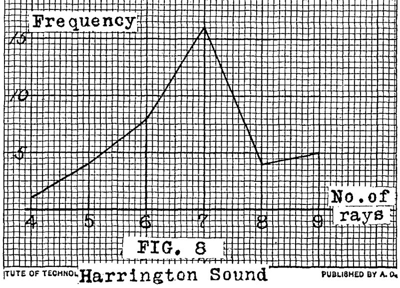


FIG. 8
Harrington Sound

taneous self-division in the laboratory. The casting off of one or more rays may at any time be induced by holding or injuring one or several rays, or by the stimulation of a ray with dilute acid applied with a pipette. The autotomy of a single ray takes place very much as described by King (1898) for *Asterias vulgaris;* the existence of a "breaking joint" in the region of the fifth ambulacral

ossicle is shown by the fact that even in preserved material the rays part very easily in that region.

The relative abundance of cases in which there are evident two groups of rays of different length indicates that, as in *Linckia* (Clark, 1913), autotomous division is a normal method of asexual reproduction.

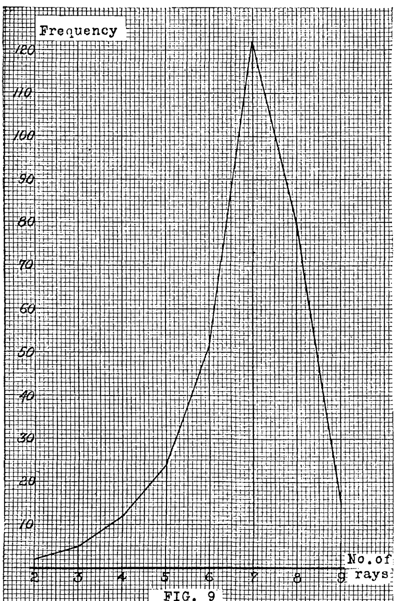


FIG. 9

Distribution of ray frequencies in the total population.

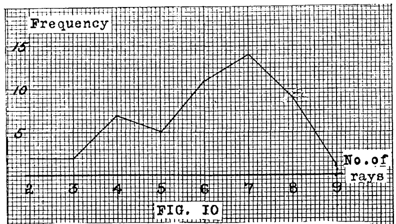


FIG. 10

Distribution of ray frequencies among individuals with all rays of equal or nearly equal length

LONG RAYS

SHORT RAYS	1	2	3	4	5	6	7	
1			1	1	4	4	2	12
2			4	2	4			10
3		1	16	18	4			39
4		6	24	28	2			60
5		3	12	4				19
6	1	2						3
	1	12	57	53	14	4	2	143

FIG. II

Relatien of long to shert rays

IV. The numerical relations of the old rays to the regenerating ones, and the topographical arrangement of the latter, yield evidence relative to certain questions in the physiology of regeneration.

(*a*) It is to be observed that the regeneration in question has taken place apart from experimental control; therefore information as to the number of rays usually present just before *Asterias* undergoes self-division must be deduced from the data at hand. The modal-ray frequency for specimens with rays of very nearly equal length is 7 (Fig. 10), but it is a question whether this appearance of equality in ray length may not be due to a

variety of conditions, especially the rapid growth of regenerated rays. The regenerating rays of *Linckia* (Clark, 1913; Monks, 1904) and the newly formed rays of multiradiate types (Ritter and Crocker, 1900) grow more rapidly than the old ones and soon reach the dimensions of the latter; this is also indicated in my series. But the correlation of the number of long with the number of short rays (using only those cases in which the two groups were clearly distinct) makes it evident (Fig. 11) that the condition in which there are 3 or 4 long rays and 4 short ones is by far the most common; and further, that the cases in which there are either 3 or 4 long rays are almost equally abundant. It seems not unlikely, then, that *A. tenuispina* usually has 7 rays before it divides, and that it divides into two parts having, respectively, 3 and 4 rays, the division-surface then giving rise, in the greater number of cases, to 4 new rays, but sometimes to 5, 3 or even 2.

If all the individuals observed had undergone autotomy and regeneration according to this scheme, then those with 7 and those with 8 rays would be expected to occur in equal abundance; 8 is next in frequency to 7, but the latter preponderates because some starfishes have probably not autotomized at all, and because all the animals which have divided do not adhere to this paradigm (see Fig. 11). Yet, in the majority of cases, 4 rays are regenerated whether there are 2, 3 or 4 long (old) rays in evidence.

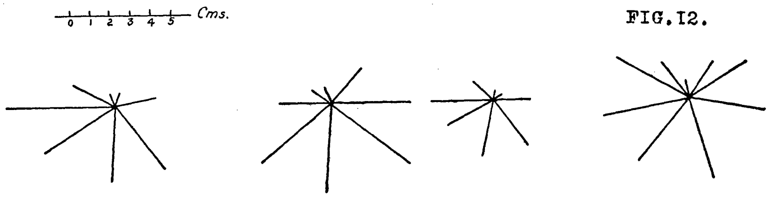
It would seem that self-division may occur at any time in the life history of *A. tenuispina*, or at least in animals of all sizes, though it is my impression, gained from handling many live individuals, that the smaller (younger ?) ones autotomize more readily than larger ones. Those showing two distinct ray groups ranged in longer ray length from 11 mm. to 65 mm. There is no evidence that autotomous divisions follow one another rapidly, or indeed that they occur more than once in any given individual.

One case was observed in which there was one long ray only, and 6 shorter ones. This may mean that a single ray can regenerate the whole body, as suggested by v.

Martens (1866, quoted by King, 1898) for this species. I have not been able to substantiate this idea by laboratory experiments, for, in my tests, single isolated rays did not live more than a few weeks.

(*b*) Newly forming rays have a tendency to appear in symmetrically disposed pairs (see Fig. 12), which gives to

FIG. 12.



DIAGRAMATIC REPRESENTATION OF THE RAYS OF FOUR ASTERIAS, SHOWING TENDENCY OF RAYS TO APPEAR IN PAIRS. Measured from the mouth along the ventral side.

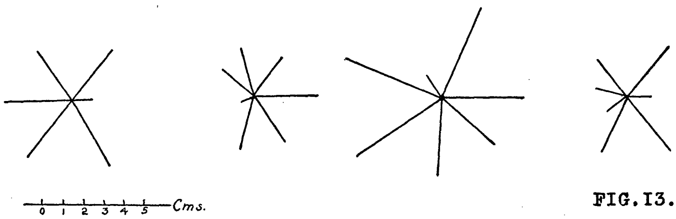


FIG. 13.

ILLUSTRATING THE RELATIONS OF NEW RAYS.

many individuals a strikingly bilateral aspect. This is accentuated by their behavior, for, in the absence of directive stimuli, they commonly move with the longest rays in advance. In moving away from the light, the locomotor movement of the group of longer rays also tends, in many cases, to produce a spurious "orientation." When placed oral side up, the larger rays exert a determining influence on the direction and manner of righting. These effects are due to the greater pedicel and muscle development of the longer, thicker, rays.

The formation of two rays at a radial cut on the disc was found by King (1900) in *Asterias vulgaris*.

V. I have suggested, above, that *Asterias* with 7 subequal rays have probably arrived at that condition by different routes. One method of ray multiplication appears to be the spontaneous addition of new rays at any point on the disc. Twelve starfish were found which showed but one ray markedly shorter than the others.

Of these, 4 had 5 long rays, 4 had 6, 2 had 7, 1 had 3 and 1 had 4 (see Fig. 11). The addition of new rays during adult life is, so far as known, unusual among starfish, excepting in the multiradiate forms (cf. Ritter and Crocker, 1900; Clark, 1907; M'Intosh, 1907). The twelve cases found in *A. tenuispina* may mean merely that a single ray has been cast off and is being regenerated, for there is found about the same percentage of naturally occurring regenerating examples of *A. vulgaris* (King, 1898; 1900). Yet I am inclined to interpret this condition as indicating the way in which the modal hepta-radiate form is derived from the fundamental penta-radiate one, or from a hexa-radiate plan, if the young of *A. tenuispina* be like the post-larvæ of *Pycnopodia* (Ritter and Crocker, 1900) previous to self-division.[3] The three smallest *Asterias* seen had 6 rays. These were subequal and 8 $\pm$ mm. long. Other specimens, slightly larger, had either 7 or 8 rays.

Cases such as those illustrated in Fig. 13 may further prove that addition of new rays occurs independently of the reformation of rays subsequent to self-division.

VI. The number of madreporites in *A. tenuispina* is also variable, as noted by Ludwig (1897, p. 358) and others. The number of madreporic bodies is certainly not correlated with the size of the starfish. One of the smallest ones seen had 8 rays and 5 madreporites, its mean ray length being 10 mm.; while the largest animal collected had 5 rays, with a mean ray length of 70 mm., and but one madreporite. The table in Fig. 14, which includes all cases in which the madreporites were counted, shows that, while the distribution of these bodies is irregular, their number is to some extent correlated with the number of rays. Ludwig gave it as his opinion that there was no correlation of this sort. The relation stands out more clearly if only those individuals having equal rays (and therefore presumably "full grown") are included (Fig. 15). Unfortunately, the number of animals is small.

Multiple madreporites were noted in 5 out of 101 ex-

[3] According to Clark's (1907) studies, the young *Heliaster* has five rays only; his results throw considerable doubt upon the correctness of the conclusions of Ritter and Crocker.

amples. Three of these showed a condition which might have arisen either by the fusion of two plates or by the

NUMBER OF RAYS

NUMBER OF MADREPORITES	2	3	4	5	6	7	8	9	
1	1	1	2	3	5	6	4		22
2		1	1	3	7	10	4	1	27
3					4	10	14		28
4					2	8	10	2	22
5					1		1		2
		2	3	6	19	34	33	3	101

FIG. 14
Correlation between number of madreporites and number of rays

NUMBER OF RAYS

NUMBER OF MADREPORITES	4	5	6	7	8	9	
1		2	1	1			4
2	1	2	1	2			6
3			1	4	2		7
4			1		2	1	4
	1	4	4	7	4	1	21

FIG. 15
Relation of ray frequency to number of madreporites in animals with rays of equal length

division of a single one. The other two cases were similar, but of trefoil form. Dissection showed, in each instance, that a single stone canal was present. Therefore these multiple plates had probably arisen by the division of an originally single one. (For a similar condition in *A. vulgaris,* see Davenport [1901].) Only one multiple madreporite was found in any one individual.

Summary

1. The modal number of rays in *Asterias tenuispina* is 7. The range in ray number is from 2 to 9.

2. The 7-ray condition is uniformly the most frequent, even in widely separated localities.

3. The modal ray number is the same for animals with subequal rays as for those with a group of regenerating rays.

4. The evidence indicates that, *most commonly, A.*

tenuispina has 7 rays before it undergoes autotomy, that it divides into 3-ray and 4-ray portions, and that each of these parts regenerates 4 rays.

5. Regenerating rays tend to appear in bilaterally disposed pairs, as regards size.

6. There is no evidence that self-division occurs often in the life of individuals, though possibly it does.

7. New rays may be added at any point on the disc.

8. The number of madreporites varies from 1 to 5, and is to some extent correlated with the number of rays; it is not correlated with the size of the animal.

9. Double or triple madreporites occur in about 5 per cent. of the individuals.

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[1] "Phataria" is an error, as pointed out by Clark (1913).